BBC RD 1977/15

BBC

RESEARCH DEPARTMENT

1974
THE QUEEN'S AWARD
TO INDUSTRY

REPORT

CEEFAX:
optimum transmitted pulse-shape

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THE BRITISH BROADCASTING CORPORATION April 1977

BBC RD 1977/15
UDC 621.397

CEEFAX: OPTIMUM TRANSMITTED PULSE-SHAPE

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Summary

The report describes an experimental investigation to determine the optimum transmitted pulse-shape for CEEFAX data signals. During transmission, the CEEFAX signal encounters many forms of destructive interference which can corrupt the transmitted data. The major sources of interference are thermal noise, multipath propagation and unavoidable instrumental imperfections within domestic receivers. The ability of the CEEFAX signal to withstand these impairments is greatly influenced by the shape of the transmitted pulse and it is therefore important that the transmitted pulse-shape is an optimum in order to maximise the CEEFAX service area.

During the investigation the performance of a wide variety of different pulse-shapes was studied. Certain assumptions which are thought to be realistic were made about the broadcast signal path and the characteristics of present and future generations of domestic receivers.

The report concludes that a pulse-shape whose spectrum has a 70% cosine roll-off is a broad optimum. The improvement in data reception gained by using this pulse-shape represents a worthwhile increase in service area.

It is also shown in the report that the greatest benefit in terms of increased service area can be achieved by improving the performance of domestic receivers. The most critical areas of receiver design are identified in the report and improvements within these critical areas are suggested.

Issued under the authority of

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Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

April 1977

(EL-126)

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CEEFAX: OPTIMUM TRANSMITTED PULSE-SHAPE

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1. Introduction

In the BBC CEEFAX system, data is transmitted serially as non-return-to-zero (NRZ) data on unused lines within the field blanking interval of the 625-line television waveform. A unified specification[1] has been agreed under the more general heading of "Teletext". (Slight modifications have recently been made to the specification, however, the general form of Teletext transmission has remained unchanged).

One aspect of the Teletext transmission system that has not yet been properly defined is the detailed spectrum of the broadcast data signals. Early work led to the use of $\sin^2$ pulses whose spectrum was truncated to fit within the nominal video bandwidth. This choice was based on fairly crude laboratory tests and measurements of group-delay distortion in domestic receivers. It was realised, at the time, that the $\sin^2$ pulse-shape may not be the optimum for the system; indeed, the Teletext specification states clearly that further work would be needed to optimise the transmitted pulse-shape.

The CEEFAX service fails whenever destructive interference has a peak-to-peak amplitude exceeding the worst-case separation between a binary '1' and a binary '0'. Field measurements have shown that noise alone is not the worst source of destructive interference. It is the combination of noise and multipath propagation that critically determines the limit on the CEEFAX service area. But in any case it is important that the worst-case separation between a binary '1' and a binary '0' is maximised in the receiver.

The resistance of the CEEFAX signal to interference is affected by the source pulse-shape and the characteristics of the transmission chain from the source to the receiver. The use of data-regenerators at many transmitters will ensure that the broadcast distribution network is transparent to the data signal, and thus the more important signal impairments will be introduced only during propagation from transmitter to receiver and within the receiver itself.

The aim of the work described in this report was to determine the optimum transmitted pulse-shape for CEEFAX in order to maximise the service area. The report makes what are thought to be realistic assumptions about the broadcast signal path. The characteristics of present and future generations of CEEFAX receivers are also taken into account.

In this report the terms 'pulse-shape' and 'spectrum-shape' are both used, the latter describing the frequency spectrum of the former.

2. Basic principles

2.1. Pulses with cosine roll-off spectra

The CEEFAX data is transmitted serially in the form of non-return-to-zero pulses with a bit-rate of 6·9375 Mbit/s (444 x line frequency). Within each bit-cell, the presence of a pulse indicates a binary '1' and the absence of a pulse indicates a binary '0'. At the receiver, the bit-stream is sampled at the bit-rate so that the individual pulses of the message can be identified.

It is important to ensure that each pulse is identified by the receiver without interference from the other pulses of the message, known as intersymbol interference. The CEEFAX signal has two discrete levels and intersymbol interference will cause the separation of the levels to be reduced and the noise margin of the signal to be lowered.

In a linear system the amount of intersymbol interference on the received signal is set by the spectrum-shaping, intentional and unintentional, applied to the signal throughout the transmission chain. In the CEEFAX system, spectrum-shaping is applied intentionally, at source, and unintentionally during propagation and within the domestic receiver. From the view-point of intersymbol interference, the distribution of the spectrum-shaping is unimportant; only the overall characteristic matters. It is convenient therefore to reduce the individual characteristics of the spectrum-shaping applied at different points in the transmission chain to a single low-pass characteristic between data source and receiver output.

Nyquist[2] has shown that a data signal which is a train of impulses with bit-rate f_b can be passed without intersymbol interference through a low-pass filter whose amplitude/frequency response is skew-symmetrical about $\frac{1}{2} f_b$. The group-delay response of the filter must be constant.

A class of filters that meets this criterion has a cosine roll-off of amplitude response with frequency. Fig. 1(a) shows the amplitude response of these filters for different rates of cut and Fig. 1(b) shows their respective impulse responses.[3] Pulse-shapes with cosine roll-off spectra were chosen as representative of all useful pulse-shapes that meet the Nyquist criterion. The percentage cosine roll-off is defined as:

$$\text{percentage cosine roll-off} = \frac{\left(\text{upper cut-off frequency} - \frac{f_b}{2}\right)}{\frac{f_b}{2}} \times 100\%$$

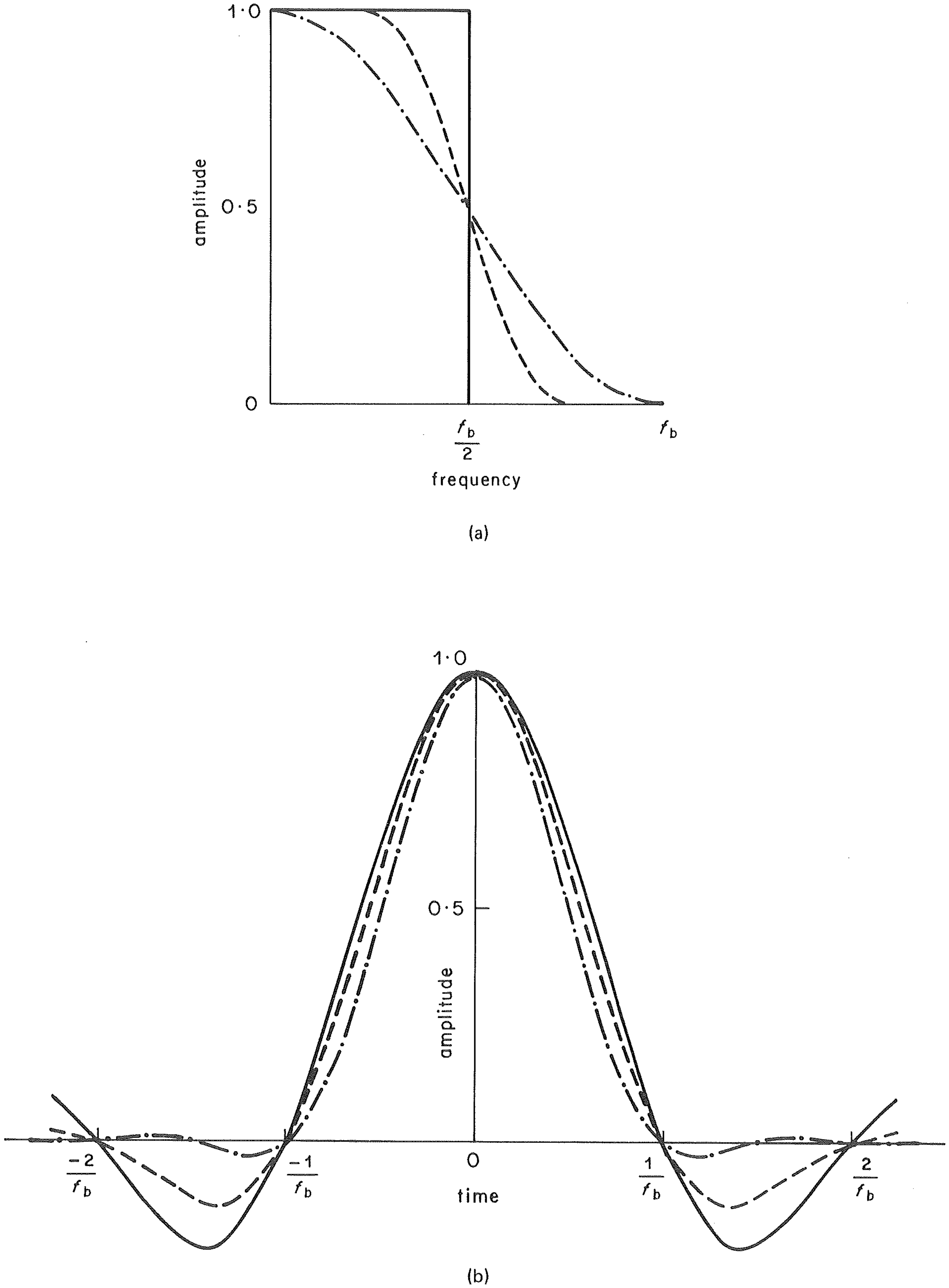


Fig. 1 - Amplitude and impulse responses of cosine roll-off filters

——— 0% cosine roll-off
- - - - 50% cosine roll-off
—·—·— 100% cosine roll-off

The impulse response of the filters has a single peak and is zero at spacings which are a multiple of the bit-period from this peak. Impulses can be sent at the bit-rate without interference between peaks.

Figs. 1(a) and 1(b) show clearly that the amplitudes of the overshoots in the impulse response increase as the bandwidth of the signal is reduced. The 100% cosine roll-off filter has an impulse response with virtually no overshoots. The 0% cosine roll-off filter has an impulse response whose first overshoot is about 20% of the amplitude of the central peak. It is also worth noting that as the bandwidth is reduced the impulse response extends over a greater time. Both these factors combine so that the peak-to-peak value of the data signal increases rapidly as the signal bandwidth is reduced.

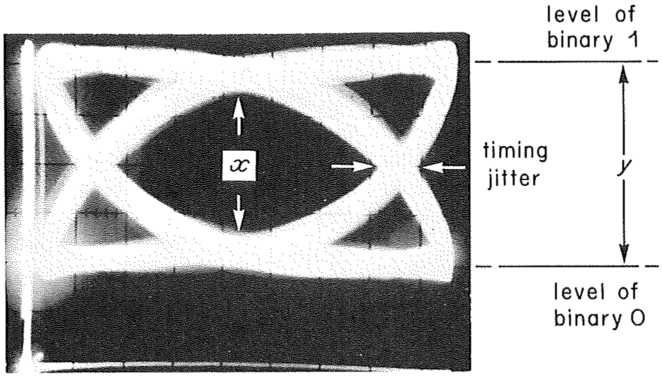
The $\sin^2$ pulse-shape currently used for CEEFAX has a 100% roll-off or raised-cosine spectrum extending to about 7 MHz but truncated to fit within the available video bandwidth of 5·5 MHz. The truncation causes some intersymbol interference and also increases the amplitude of the pulse overshoots.

2.2. A measure of performance

It was necessary to establish a convenient and realistic measure of performance for Teletext transmission systems, to perform the tests described in this report. The 'eye-height'[3] of data was used as such a criterion since it is directly related to the amount of destructive interference which the data signal can stand before errors arise in the decision-making circuits of the data decoder. An example of an eye-pattern is shown in Fig. 2. This eye-pattern was produced on an oscilloscope using a sinusoidal horizontal sweep at one quarter of the bit-rate frequency, with the data signal under examination applied to the vertical input. Four bit-periods are displayed during each horizontal cycle, two centrally (during forward and return sweeps) and one at each side. 'Eye-height' is taken as the percentage ratio of the minimum opening at the centre of the eye-pattern to the separation between the levels of continuous binary '1's and '0's on the same display. It is assumed here that the sampling of the signal will be set to take place at the centre of the eye-pattern.

The resistance to interference of Teletext data signals also depends on other factors besides the eye-height of the data. One such factor is the distribution of the '1' and '0' signal levels at the sampling instant. The minimum separation of these levels denoted by the eye-height is only reached for certain worst-case data sequences. The majority of data sequences would have a greater noise immunity than these worst-case sequences. Hence, taking eye-height as a measure of performance leads to a pessimistic view of the noise resistance of the data. However, the difference is small and, more important, it is consistent at the good eye-heights dealt with in this report.

Moreover, the use of eye-height also neglects the effect of the Teletext receiver on the nature and magnitude of added noise. Such noise is not normally present when eye-height measurements are made. Now, a non-ideal frequency response in the receiver will reduce data eye-height. But it may also change the level of the noise and interference present which tend to corrupt the data signal. Hence it is possible for the loss of noise immunity of the data signal caused by a loss of eye-height to be partially compensated by a corresponding reduction in the level of the noise and interference. However, for the small impairments considered in this report, eye-height will be the dominant factor.



eye height = $\frac{x}{y}$

Fig. 2 - Example of an eye-pattern display

Various aspects of the operation of the data-acquisition circuitry in the Teletext decoder will also affect the resistance to interference of the received data. For instance, data must be sampled at the right instants for maximum interference immunity. The jitter on the sampling clock-pulses depends, among other factors, on the timing jitter of the threshold-crossing instant of the data waveform. However, the degradation in performance due to timing jitter will be very small with a well-designed decoder, provided the input timing jitter on the data waveform is sufficiently small. This condition was satisfied in all the tests described in this report.

At a given data eye-height, some Teletext decoders with better data-acquisition circuitry, will perform better than others. However, it is reasonable to assume that all decoders will function better with a better data eye-height, provided that other factors such as input timing jitter, and peak-to-peak value of the input data signal are constrained to reasonable levels.

For these reasons eye-height was considered a realistic measure of the immunity to interference of the data signal, for the tests described in this report. It must be stressed, however, that this would not be true where eye-heights are small and impairments severe.

3. Selecting the optimum pulse-shape

3.1. General

Selecting an optimum pulse-shape for CEEFAX is a complicated procedure. There are many different approaches to the problem and they need not lead to the same final pulse-shape.

One approach that was tried initially was to divide the possible impairments to the data into categories and for each category find a pulse-shape that gave 100% eye-height. It was hoped at the end of these experiments to find some common ground between the various pulse-shapes and thereby select an optimum. In practice, the results from using this approach were very inconclusive. Dividing all the possible impairments to the data into categories was found to be quite difficult. All forms of anomalous propagation and receiver imperfections had to be considered. The results of this early work was a large number of pulse-shapes, each one of which was an optimum for a particular category of impairment. Unfortunately, they were so diverse that it was found to be impossible to combine them into a single optimum. It was nevertheless noticed that none of these separate optima was very critical.

So this early work, although generally inconclusive, did cast some light on the subject. First, the possible impairments to the data signal are so diverse that if there is an optimum pulse-shape, it is likely to be a broad optimum. Secondly, the only common factor between the various pulse-shapes, was that their spectra fitted more fully within the nominal video bandwidth than the 100% cosine roll-off or raised-cosine spectrum of the current $\sin^2$ pulse-shape.

On the basis of the early work, it was decided to consider only pulse-shapes whose spectrum had a cosine roll-off. Since it was expected that the optimum pulse-shape would be a broad optimum it is unlikely that restricting the experiments to one class of pulse-shapes would lead to a significant error. Also, by using this class of pulse-shapes it is possible to explore fully the relationship between data eye-height and the way in which the pulse spectrum fits into the nominal video bandwidth.

Certain constraints were imposed on the experimental work, besides the restriction to a class of pulse-shapes. The spectrum of the data was to be restricted at its upper frequencies to fit into the available 5 MHz bandwidth of television Systems B and G. The separation in levels between a continuous series of binary '0's and a continuous series of binary '1's in the transmitted data was held constant when comparing the various pulse-shapes. This meant that the energy of the CEEFAX signal was nearly the same for the various pulse-shapes though the peak-to-peak value of the data signal could vary.

From the point of view of television transmission and reception, the peak-to-peak excursion of the data signal is not very important, although it can affect the visibility of the data signal on misaligned television receivers. It can also cause non-linearity or interfere with the action of sync. separators in receivers. However, a constraint was imposed that the peak-to-peak value of the data signal should not exceed 140% of the separation in level between continuous binary '1's and binary '0's. A data signal with a peak-to-peak value constrained within this bound at source was thought unlikely to impair television reception, even with quite severe waveform distortion due to multipath propagation or other effects. Fig. 3 illustrates the level parameters of the CEEFAX data signal in relation to the television waveform.

3.2. Effect of transmitted pulse-shape with a perfect transmission chain of finite bandwidth

A 'perfect transmission chain' is one which is linear, and has no amplitude or group-delay distortion below its cut-off frequency.

Measurements of the effects of a perfect transmission chain with 5 MHz bandwidth were made using various items of purpose-built CEEFAX test equipment. The test set-up is illustrated in Fig. 4. A 'test pages generator'[4] was used to generate a CEEFAX data signal which was processed by a transversal filter (see Appendix I), used to set-up the various data pulse-shapes. The output of the transversal filter was band-limited, using a high-quality group-delay-corrected low-pass filter with a –3 dB response at 5 MHz. Eye-height measurements and peak-to-peak value measurements were made using an eye-height display unit.[5] The form of the display has been described in Section 2. The variation in eye-height and peak-to-peak values for data signals using various pulse-shapes with cosine roll-off spectra, truncated at 5 MHz, were measured

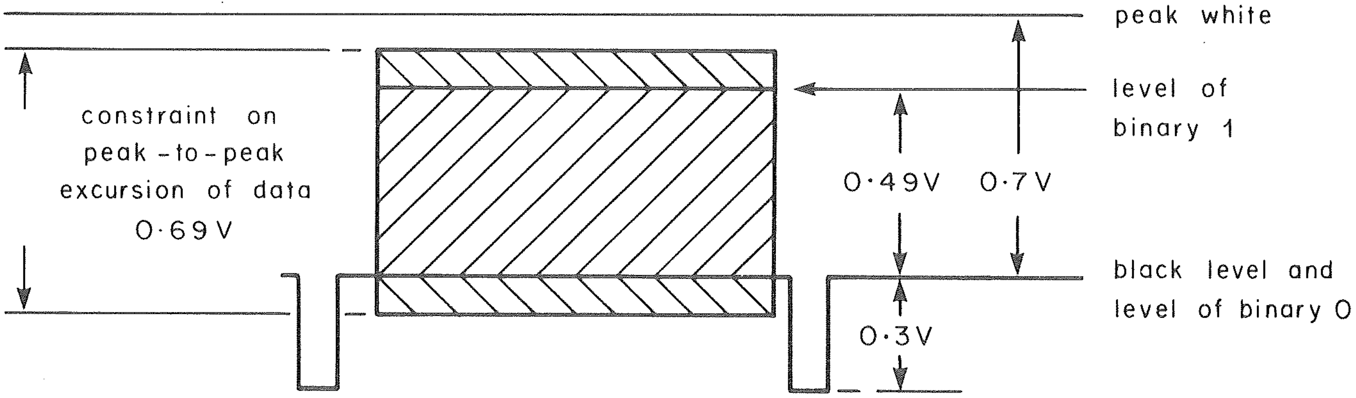

peak white
level of binary 1
constraint on peak-to-peak excursion of data 0·69 V
0·49 V
0·7 V
black level and level of binary 0
0·3 V

Fig. 3 - Level of data on television lines

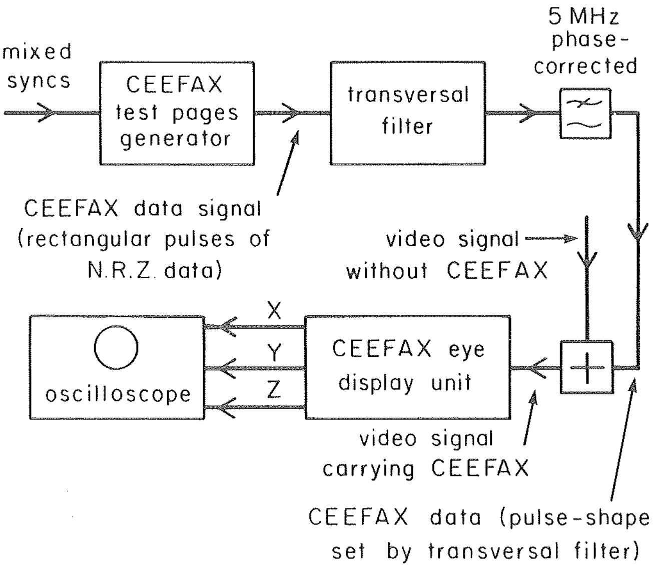

mixed syncs
CEEFAX test pages generator
transversal filter
5 MHz phase-corrected
CEEFAX data signal (rectangular pulses of N.R.Z. data)
video signal without CEEFAX
X
Y
Z
oscilloscope
CEEFAX eye display unit
video signal carrying CEEFAX
CEEFAX data (pulse-shape set by transversal filter)

Fig. 4 - Method for measuring eye-height and peak-to-peak value of CEEFAX data

and the results are illustrated in Fig. 5. The values of eye-height and peak-to-peak values are expressed as a percentage of the separation between continuous binary '1's and binary '0's.

Fig. 5 illustrates that the eye-height improves as the percentage cosine roll-off decreases (i.e. the rate of cut of the data spectrum increases). This is because the spectrum of the data pulse fits more and more fully into the available bandwidth. A pulse-shape whose spectrum has a 44% cosine roll-off fits fully into a 5 MHz bandwidth and should therefore provide a 100% eye-height. The eye-height was measured as 96% (see Fig. 5). This indicates a 4% loss due to imperfections in the experimental equipment. Fig. 5 also illustrates that the peak-to-peak value of the data signal increases rapidly as the percentage roll-off decreases.

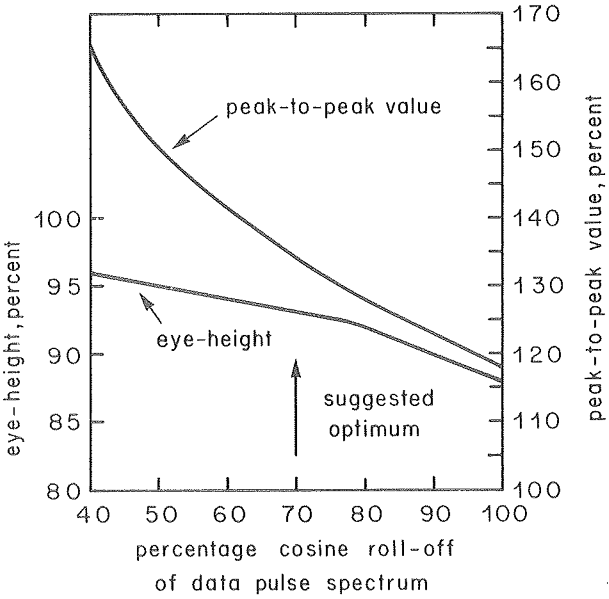


Fig. 5 - Eye-height and peak-to-peak value of CEEFAX data bandlimited to 5 MHz, plotted against the percentage cosine roll-off of the data pulse spectrum

3.3. Optimum data pulse-shape in the presence of multipath propagation

The influence of multipath propagation, or echoes, was studied in selecting the optimum data pulse-shape, because it was found during field trials that multipath propagation greatly influenced the CEEFAX service area. The loss of eye-height that can be caused by multipath propagation depends on the peak-to-peak value of the data signal (with the separation between the levels of binary '1' and binary '0' held constant at the signal source). The larger the peak-to-peak value of the data signal, the greater the potential loss of eye-height. Hence reducing the percentage roll-off of the data pulse spectrum (i.e. making the roll-off steeper) increases the potential loss of eye-height due to multipath propagation. However, it also increases the eye-height in the absence of multipath interference. These opposing effects lead to a pulse-shape which results in maximum eye-height under specified multipath conditions.

Measurements were made to determine the pulse-shape which gave the greatest eye-height in a 5 MHz channel in the presence of the strongest echo expected in practice (30%), interfering in the most destructive way. The experimental arrangement used is shown in Fig. 6. For the arrangement shown in Fig. 6, the variable attenuator was adjusted so that the delayed signal was 30% of the direct signal. The variable delay was adjusted to give minimum eye-height which was the value recorded for each pulse-shape. Fig. 7 shows eye-height plotted against the percentage roll-off of the data pulse spectrum. The eye heights in Fig. 7 are expressed as a percentage of the separation between the levels of binary '1' and binary '0' in the absence of multipath propagation. A pulse whose spectrum has a 70% to 80% cosine roll-off is indicated as a broad optimum.

There are other reasons why a cosine roll-off of

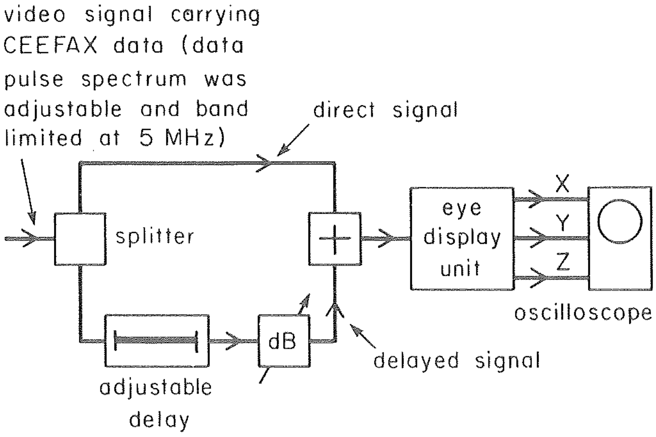

video signal carrying CEEFAX data (data pulse spectrum was adjustable and band limited at 5 MHz)
direct signal
splitter
eye display unit
X
Y
Z
oscilloscope
dB
delayed signal
adjustable delay

Fig. 6 - Method for measuring eye-height of CEEFAX data signals in the presence of multipath interference

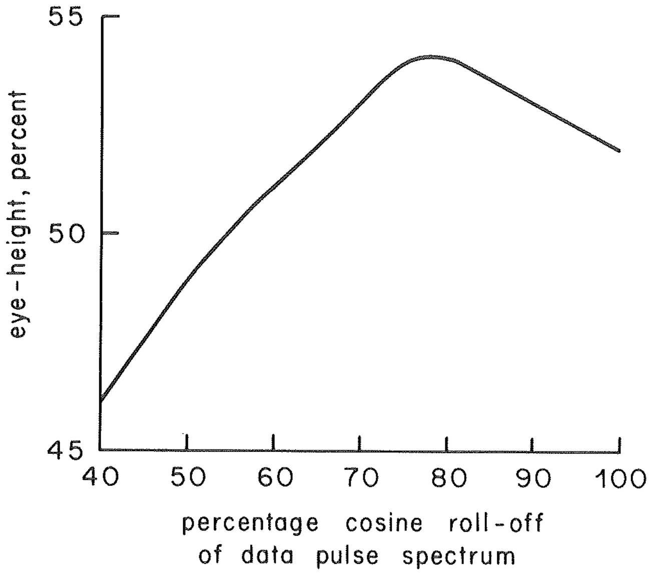


Fig. 7 - Eye-height with 30% destructive multipath interference plotted against percentage cosine roll-off of the data pulse spectrum

about 70% is attractive. It gives a peak-to-peak value of data signal which is 135% of the separation between the levels of binary '1' and binary '0', (see Fig. 5), and an eye-height of 93%. Increasing the percentage cosine roll-off causes significant loss of eye-height without very much reduction in the peak-to-peak value. Reducing the percentage roll-off below 70% brings diminishing returns in eye-height increase, and rapidly increasing overshoots.

A pulse-shape whose spectrum has a 70% cosine roll-off provides a data output which meets the constraint on peak-to-peak value. Even with a 30% echo the peak-to-peak value cannot rise to a level which is likely to interfere with television reception.

4. Domestic receivers of the future

4.1. General

Any optimum pulse-shape that is recommended by this report must suit high-quality receivers of the type that will be in use when CEEFAX becomes an established service. Such a receiver was simulated in the laboratory to study its effect on CEEFAX data signals.

The distortions in receivers affecting Teletext reception, and means by which the distortions may be overcome in receivers of the future are discussed in Appendix II. A brief summary is presented here in order to justify the laboratory simulation of receivers of the future.

(i) Amplitude and group-delay distortion introduced in the r.f. tuner, the i.f. filter and its associated amplifiers, and the demodulator and video circuitry. The i.f. filter is responsible for most of the imperfections.

(ii) Non-linear distortion introduced mainly in the demodulator.

It was assumed that, in Teletext receivers of the future, these shortcomings would be dealt with as follows. The i.f. filter would be a surface-acoustic-wave (SAW) device. These filters work on the transversal-filter principle, and can therefore give a flat group-delay response without any special compensation. They also provide an accurately reproducible amplitude response, subject to a much smaller spread in production than conventional lumped-element filters. The tuning point will probably be accurately maintained in relation to the i.f. response, by using either sophisticated automatic-frequency-control circuits or a frequency-synthesised local-oscillator. The r.f. tuner, demodulator and video circuitry will probably be designed to introduce negligible amplitude and group-

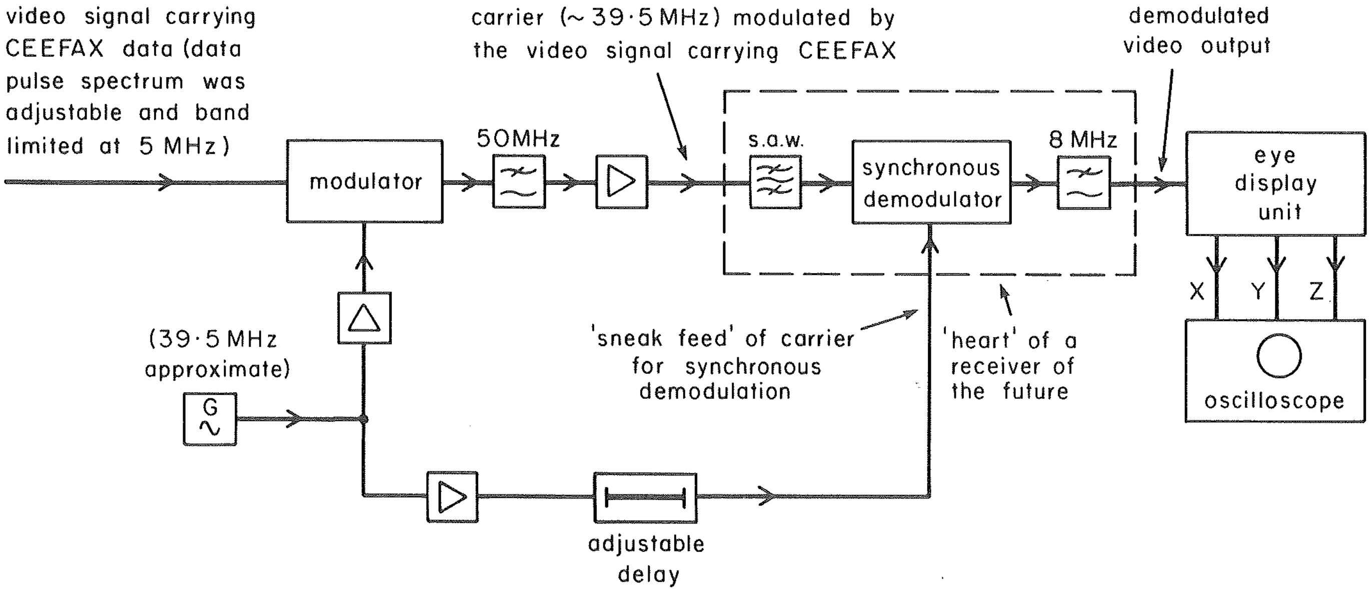

video signal carrying CEEFAX data (data pulse spectrum was adjustable and band limited at 5 MHz)
modulator
50MHz
carrier (~39·5 MHz) modulated by the video signal carrying CEEFAX
s.a.w.
synchronous demodulator
8 MHz
demodulated video output
eye display unit
X
Y
Z
oscilloscope
(39·5 MHz approximate)
G
'sneak feed' of carrier for synchronous demodulation
'heart' of a receiver of the future
adjustable delay

Fig. 8 - Simulation of high-quality receivers of the future

delay distortion. Non-linearity will probably be reduced to negligible proportions by the use of synchronous detection, with perhaps a phase-locked-loop for carrier recovery. The receivers just described may not be on the market for some time, but in selecting the optimum Teletext pulse-shape it was thought best not to prejudice performance in order to gain any advantage in the shorter term with receivers of poor quality.

4.2. Selecting an optimum pulse-shape for receivers of the future

Experimental arrangements were assembled to simulate high-quality future generation receivers with the characteristics described in the last section. They consisted of present-generation SAW television i.f. filters made by UK manufacturers, whose output was amplified and fed to a true synchronous demodulator as shown in Fig. 8. The spectrum-shaping effects of the r.f. tuner, the demodulator, and the video circuitry were neglected in the simulation. The effect of non-linearity was also neglected. A small amount of non-linearity, if present in future Teletext receivers will not invalidate the choice of the optimum data pulse-spectrum made using the laboratory simulation of a receiver, since all the pulse-shapes will be almost equally affected by the non-linearity. This was confirmed by an experiment which is described later in Section 4.4.

Three SAW filters were used in the laboratory simulation. The amplitude responses of the three filters called A, B and C are illustrated in Figs. 9, 10 and 11 respectively. The frequency to which the vision carrier was tuned when using each filter is also indicated in the figures. The baseband video amplitude response for each of the filters, shown in Fig. 12, was obtained by calculation from the i.f. response. The calculation was made assuming that the i.f. filters had no group-delay distortion in the vestigial region. This assumption is reasonable since all the filters had a virtually constant group-delay response.

Measurements of eye-height, and peak-to-peak value were then made on data signals using the simulated receivers described above, for CEEFAX data with various pulse-shapes. These measurements were made using the arrangement of Fig. 8, with the various items of CEEFAX test equipment mentioned earlier. The results obtained in each case are plotted in Fig. 13 and Fig. 14. The data eye-height of each of the three simulated receivers, in the presence of a 30% echo interfering in the most destructive way is plotted for a range of data pulse-shapes in Fig. 15. Once again a consideration of eye-height, peak-to-peak value, and multipath performance indicates that a data pulse-shape having a 70% cosine roll-off spectrum is a broad optimum.

4.3. Predistortion

Predistortion of the transmitted spectrum to com-

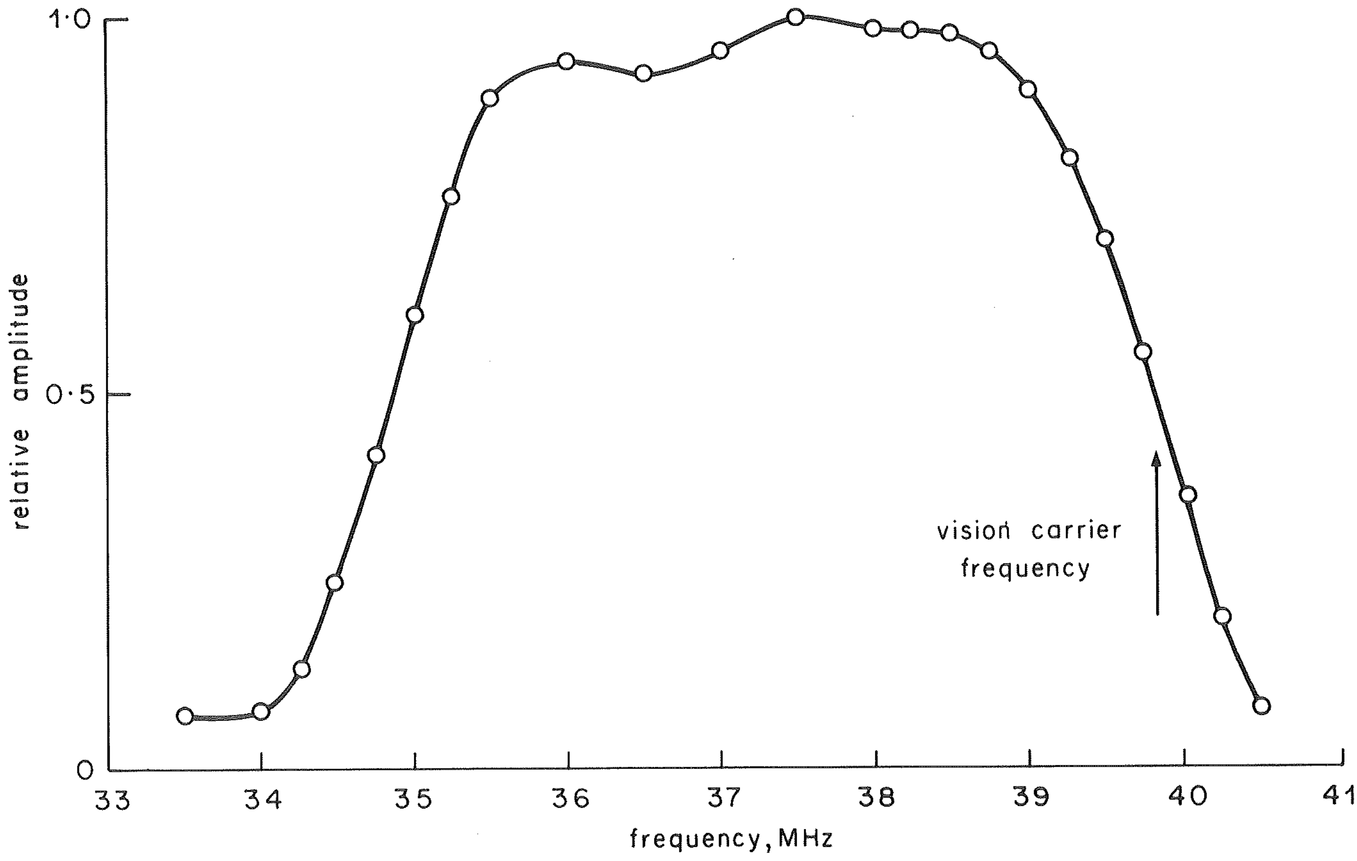


Fig. 9 - Amplitude response of SAW television i.f. filter 'A'

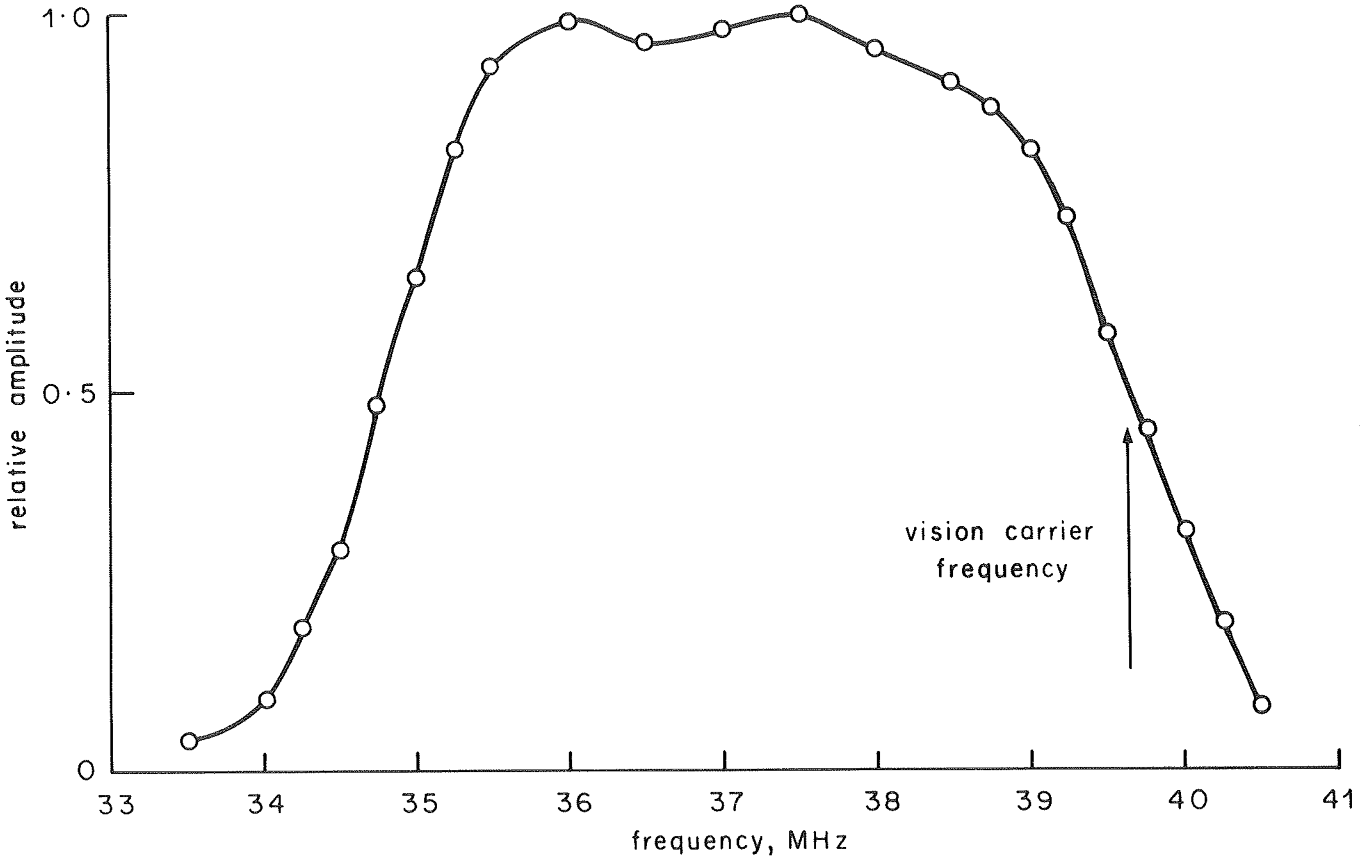


Fig. 10 - Amplitude response of SAW television i.f. filter 'B'

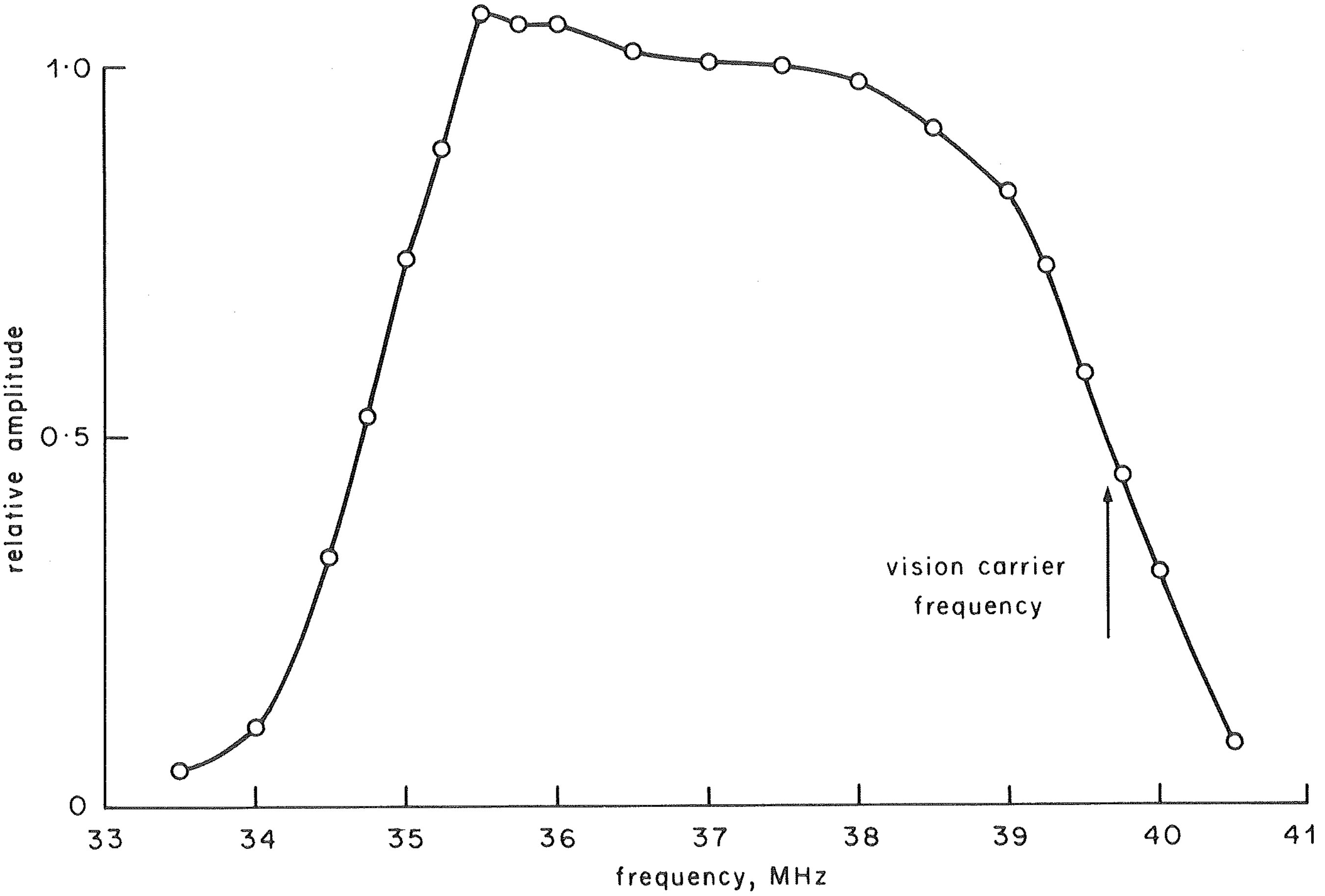


Fig. 11 - Amplitude response of SAW television i.f. filter 'C'

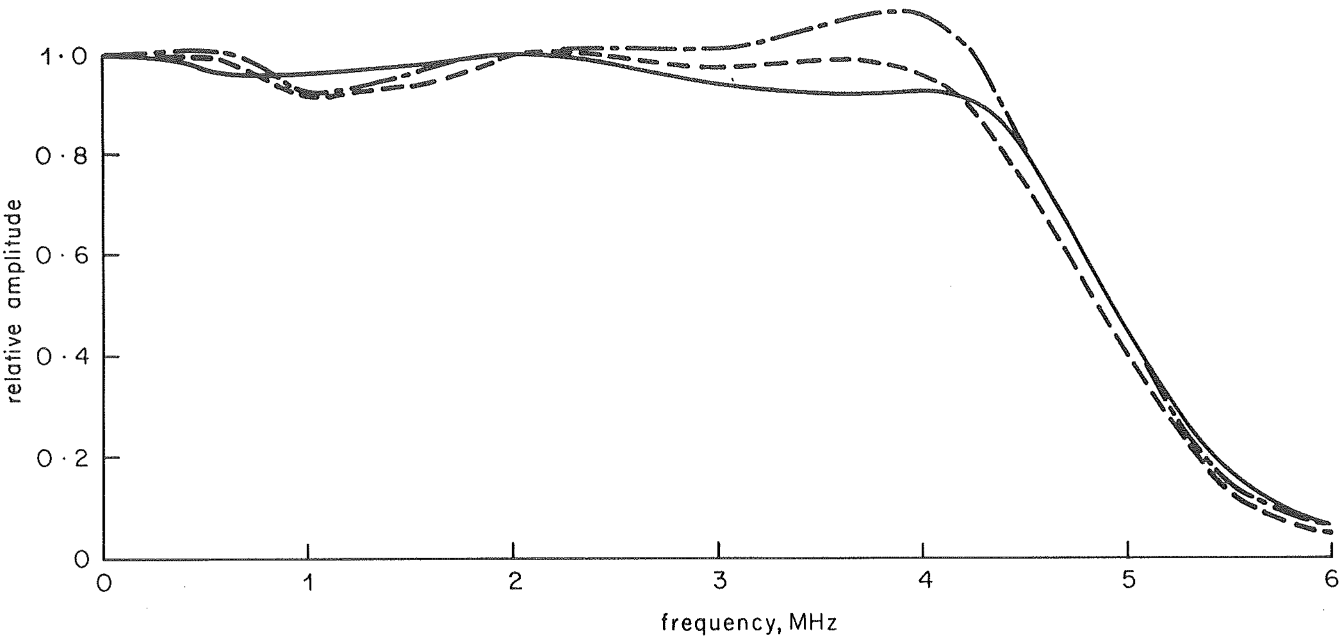


Fig. 12 - Computed baseband frequency response for SAW television i.f. filters

pensate receiver characteristics was considered. However, predistortion is not recommended for the following reasons. The loss of eye-height caused by the receivers described in Section 4.1., that could be compensated by predistortion was mainly due to

(i) ripples in the low-frequency end of the baseband video response (up to 3·5 MHz)

and (ii) a curtailed high-frequency response.

The former was the more important cause but was difficult to compensate because of the variation from one receiver to another. Compensation at high video frequencies was possible but it was thought that the benefit gained was too small to justify its use and it would prejudice future improvements in receiver performance.

4.4. The effect of non-linearity

In most television receivers the demodulator is the

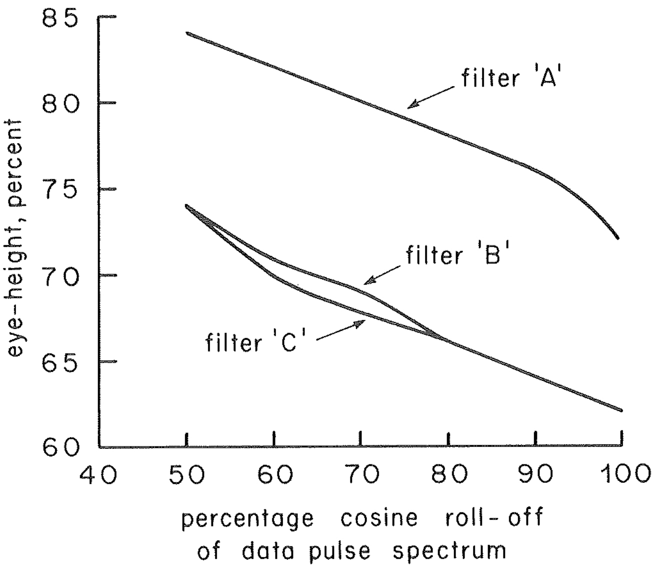


Fig. 13 - Eye-height plotted against percentage cosine roll-off of the data pulse spectrum using the three simulated receivers

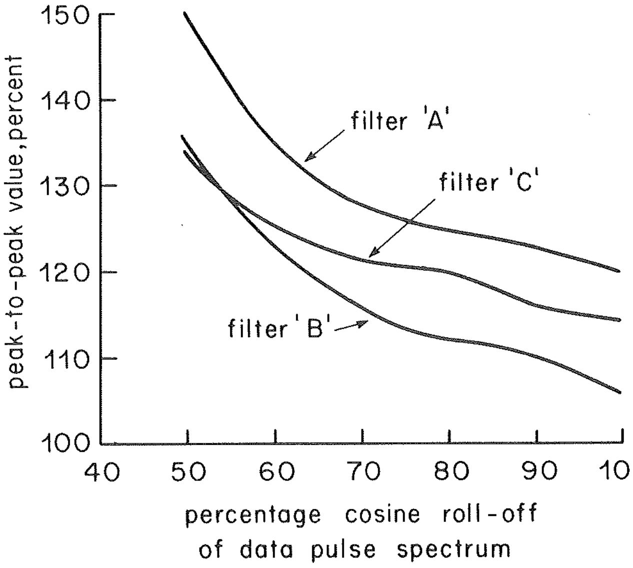


Fig. 14 - Peak-to-peak value of the data signal plotted against percentage cosine roll-off of the data pulse spectrum using the three simulated receivers

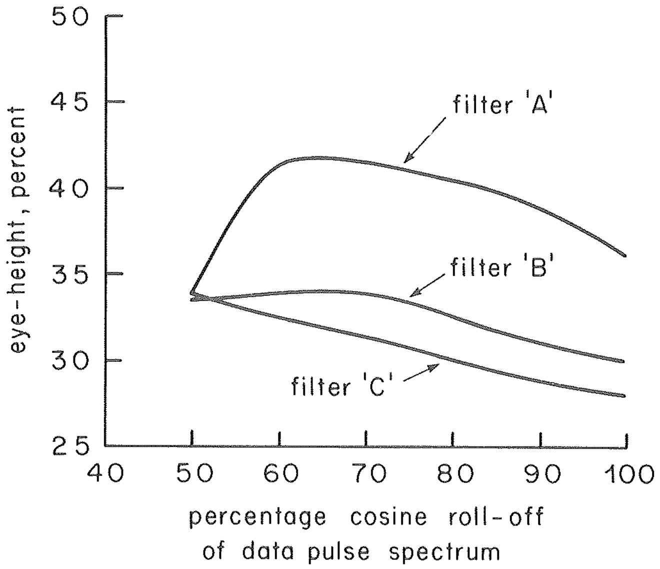


Fig. 15 - Eye-height in the presence of 30% destructive multipath interference plotted against percentage cosine roll-off of the data pulse spectrum for the three simulated receivers

main source of non-linearity. The reasons for this and the remedies are discussed in Appendix II, and it is hoped that this type of non-linearity will be greatly reduced in receivers of the future. However, a simple experiment was done to determine if the type of non-linearity found in present-generation demodulators would affect the choice of an optimum pulse-shape.

In order to assess the effect of non-linearity, a typical commercial integrated-circuit demodulator was used to demodulate the output signal from SAW filter 'A', in place of the near ideal synchronous detector shown in Fig. 8. The demodulator was of the 'quasi-synchronous' variety which synchronously demodulates the signal using a carrier obtained by passing the i.f. signal through a tank circuit centred on the carrier frequency and then limiting the output signal.

The eye-height obtained with various pulse-shapes using this demodulator is compared in Fig. 16 with that obtained using the synchronous detector of Fig. 8. It will be observed that there is a consistent reduction in eye-height of about 12% for all pulse-shapes; some of this loss (3 or 4%) was due to attenuation of high video frequencies. The results show that while this type of non-linearity results in a loss of eye-height it does not affect the choice of an optimum pulse-shape.

5. The optimum pulse-shape – comparison with earlier transmission standard

5.1. General

It can be seen from the results presented so far that a pulse-shape whose spectrum has a 70% cosine roll-off is indicated as a broad optimum because

(i) it offers the best performance in the presence of multipath propagation

(ii) it offers the best compromise between eye-height and peak-to-peak value of the data signal, and

(iii) it is a broad optimum for use with high-quality receivers of the future.

Before recommending the use of the optimum pulse-shape on CEEFAX broadcasts, it was necessary to ascertain that this optimum pulse-shape did not seriously degrade performance with present generation receivers.

5.2. Eye-height measurements

Three receivers were tested with the new optimum pulse-shape and with the two pulse-shapes used to date in CEEFAX broadcasts. The results of these tests are shown in the table opposite. (The two pulse-shapes used in present broadcasts had 100% cosine roll-off (raised-cosine) spectra extending up to 7 MHz which was truncated initially at 4·5 MHz and, later in the tests, at 5·5 MHz). 'B' is an example of a high quality present generation television receiver while 'A' and 'C' are more typical of present generation receivers.

5.3. "Buzz-on-sound"

The effect of the data pulse-shape on 'CEEFAX buzz-on-sound' was studied. CEEFAX buzz occurs due to non-linearity in the receiver (usually in the demodulator) that can distort the CEEFAX data signal so as to produce

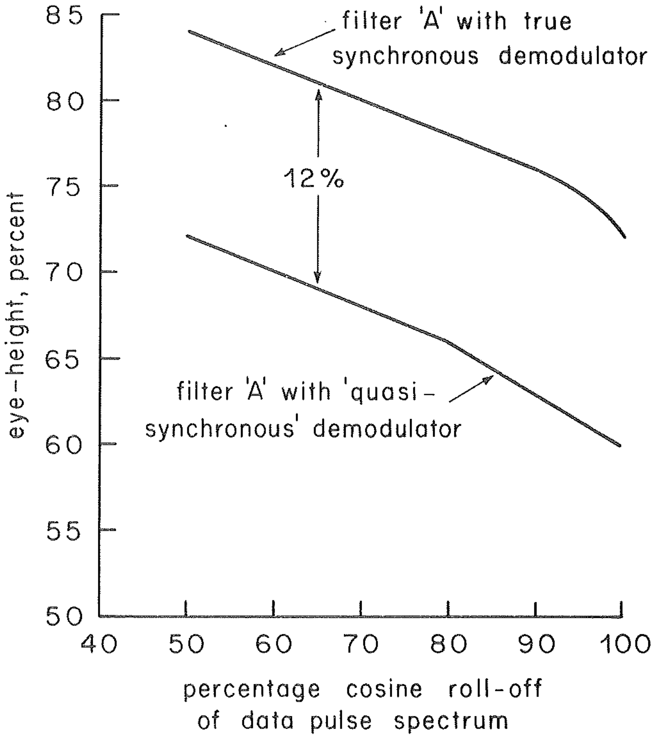


Fig. 16 - The effect of demodulator type on eye-height with one of the simulated receivers

Receiver	Eye-height		
	Pulse with 70% cosine roll-off spectrum (truncated at 5·0 MHz)	Pulse with 7 MHz raised-cosine spectrum	
		Truncated at 4·5 MHz	Truncated at 5·5 MHz
A	62%	52%	58%
B	76%	72%	70%
C	64%	58%	58%

energy near the sound inter-carrier frequency of 6 MHz. The vast majority of receivers suffer no impairment of the sound signal when fed with a normal CEEFAX signal and a sound carrier at the correct relative level. It is necessary to increase the depth of modulation of the CEEFAX data or reduce the level of the sound carrier to induce buzz in typical receivers.

To compare the effect of the various data pulse-shapes from this point of view, the depth of modulation of the CEEFAX data signal was increased above the normal level until buzz was just audible on a receiver which was highly susceptible to the effect. A $\sin^2$ pulse whose spectrum was truncated at 5·5 MHz was used for this test. The pulse-shape was then changed keeping constant the separation in level between continuous binary '1's and continuous binary '0's. A $\sin^2$ pulse whose spectrum was truncated at 4·5 MHz and the optimum pulse-shape were also tried. Four skilled observers could detect no perceptible difference in the level of CEEFAX buzz produced by the three different pulse-shapes.

6. The design of Teletext receivers

It is evident that the optimum data pulse-shape discussed above can give a small but significant improvement in CEEFAX reception under most conditions when compared with the pulse-shapes used so far.

However, a much larger improvement can be realised by improving the design of Teletext receivers. The design of Teletext receivers is discussed in Appendix II. It is important that the performance of receivers should be improved in order to maximise the CEEFAX service area.

It is worth considering the effect of a poor receiver on reception of data signals to understand why this is so. In the absence of noise and interference, error-free data reception is possible, in theory, with any eye-height above 0%. Hence a 'poor' receiver which gives (say) a 20% eye-height with unimpaired signals will work perfectly in certain locations which receive unimpaired, noise-free signals. However, a small amount of multipath propagation or noise would render data reception impossible. Hence a poor receiver will completely fail to receive data in certain locations, though it may receive error-free data in other locations. The effect of using poor receivers is not therefore a consistent degrading of the quality of reception as in analogue television, but a complete failure of data reception at certain locations within the specified service area.

7. Conclusions and recommendations

The report has shown that the reception of CEEFAX data signals can be improved by using the suggested optimum transmitted pulse-shape. Although the improvement in received data eye-height compared to the existing pulse-shape is only about 5%, this represents a worthwhile increase in service area.

It is recommended that CEEFAX data signals should be broadcast in future with a pulse-shape whose spectrum has a 70% cosine roll-off truncated at 5 MHz.

To ensure that the data waveform is not degraded by the television network it is essential to use data-regenerators with integral pulse-shaping filters at many points in the network, probably at main transmitting stations. Otherwise most of the benefits of using the optimum pulse-shape at the input to the network would in many cases be lost.

Whilst the recommended pulse-shape will result in improved performance with most Teletext receivers, receiver design must be improved further to obtain all the potential benefits. Assuming that the necessary data regenerators are used, improvements in receiver design are the best way of achieving the maximum CEEFAX service area. The report has discussed at some length the more critical areas of receiver design. Improvements within these critical areas have also been suggested.

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APPENDIX I

Transversal pulse-shaping filter

For much of the experimental work described in this report, it was necessary to generate CEEFAX data with a wide variety of pulse-shapes. One method would be to use conventional lumped-element filters with a different filter for each pulse-shape. The amplitude response of each filter would have to be accurately controlled for the correct pulse-shape to be produced. Also, the group-delay response of each filter would have to be constant within the signal bandwidth. Seven different pulse-shapes were required in the experiments and considerable time would have been spent designing and constructing the necessary filters.

A simpler solution to the problem of pulse-shaping was to use a continuously-variable transversal-filter. The basic elements of a transversal filter are shown in Fig. 17(a); the input signal is applied to a tapped delay-line and the output is formed by summing the output signals from the taps, suitably weighted. The weighting is achieved by setting the coefficients of the multipliers fed by each tap.

When a unit impulse is applied to the input of the transversal filter, the output is a series of impulses spaced by the tap interval 'T'. The height of each impulse is controlled by a coefficient of the tap multipliers. The output from the filter can be considered as being a series of samples of a particular pulse-shape as shown in Fig. 17(b), where the sampling frequency is the reciprocal of the tap interval. If the output of the transversal filter is passed through an ideal low-pass filter with a cut-off frequency of half the sampling frequency a continuous waveform pulse is produced as shown in Fig. 17(c). This pulse has the same shape as the "envelope" of the impulse waveform shown in Fig. 17(b), as a direct consequence of Nyquist's Sampling Theorem.[6]

Any pulse-shape can be produced by the transversal filter, provided the effective sampling frequency is greater than twice the highest required output frequency component and there are sufficient taps on the delay line to cover the duration of the desired pulse.

A schematic diagram of the experimental 10-tap transversal filter is shown in Fig. 18(a). The incoming CEEFAX data signal, in non-return-to-zero form, is con-

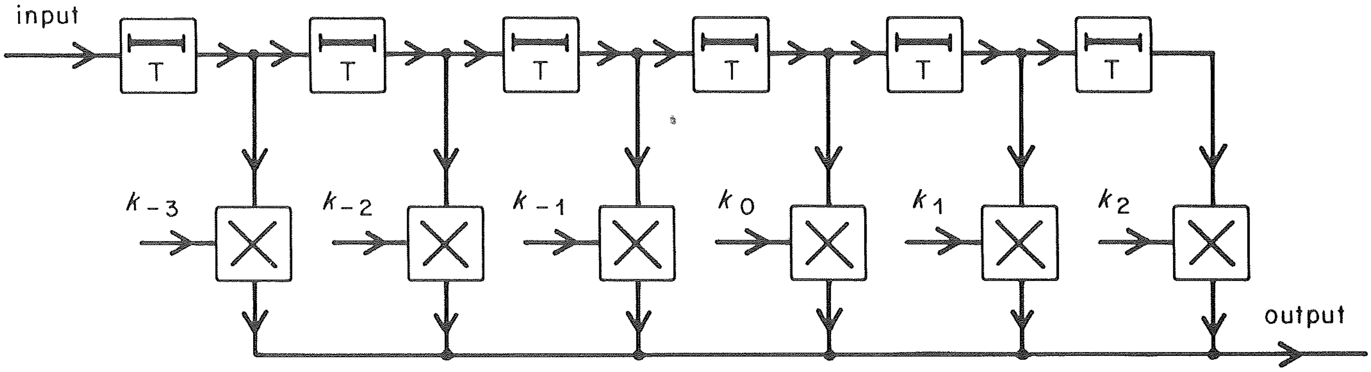


Fig. 17(a) - Ideal transversal filter

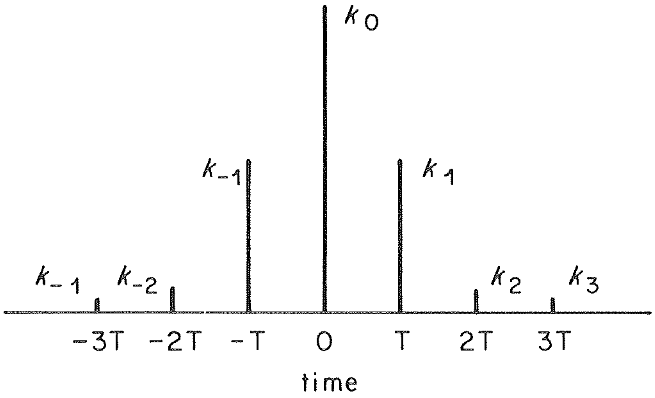


Fig. 17(b) - Output from transversal filter for unit impulse input

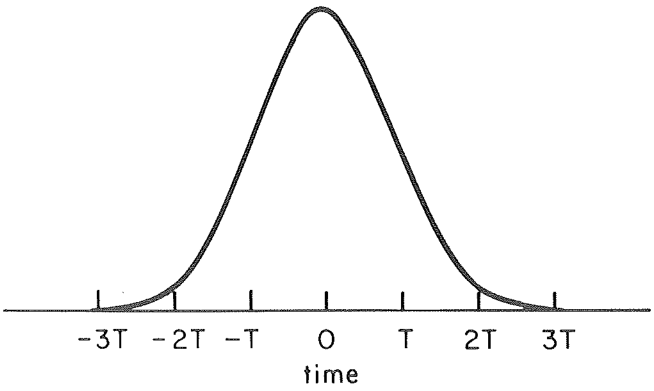


Fig. 17(c) - Output from transversal filter after passing through an ideal low-pass filter with cut-off frequency (1)/(2T) Hz

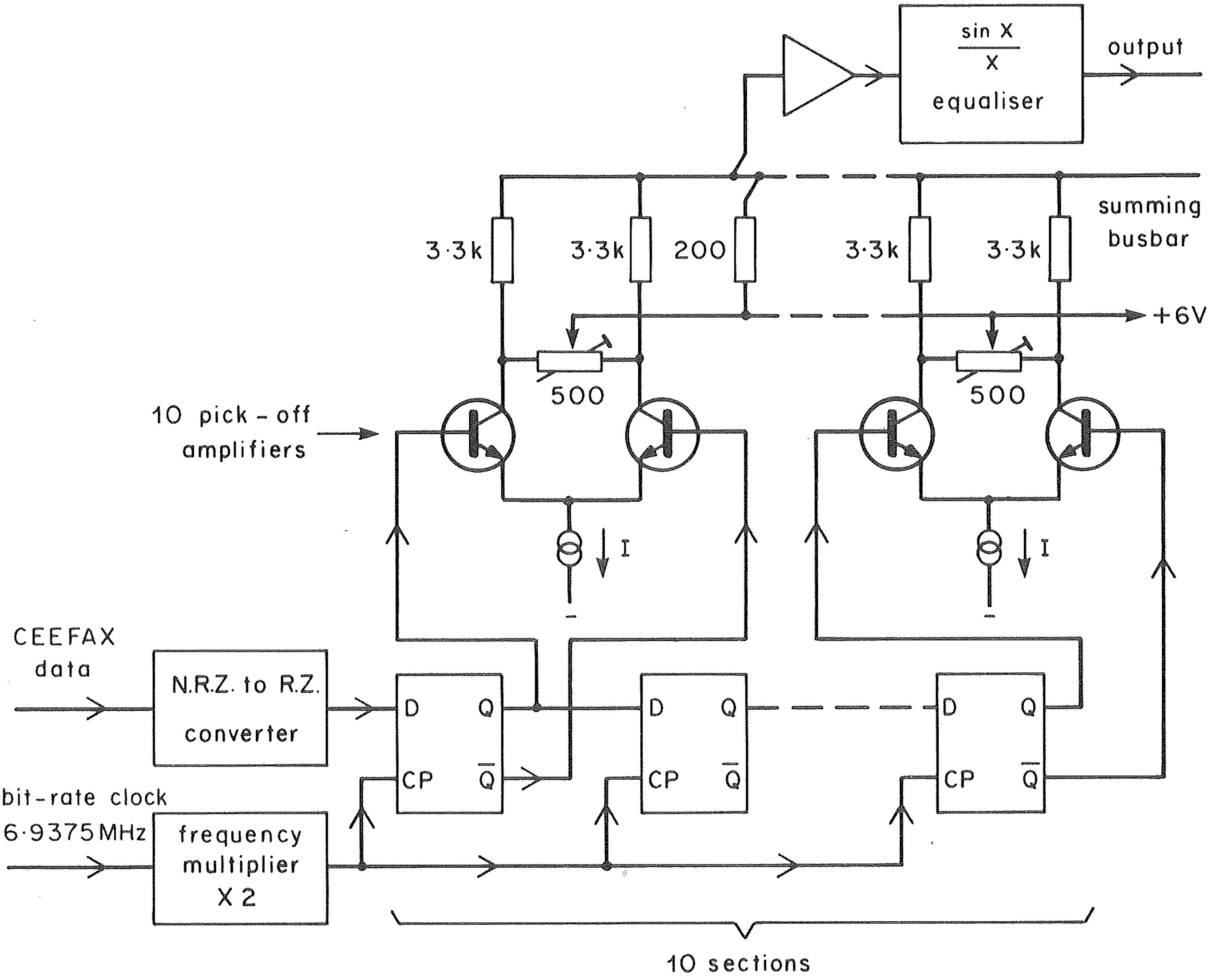


Fig. 18(a) - Schematic diagram of experimental transversal filter

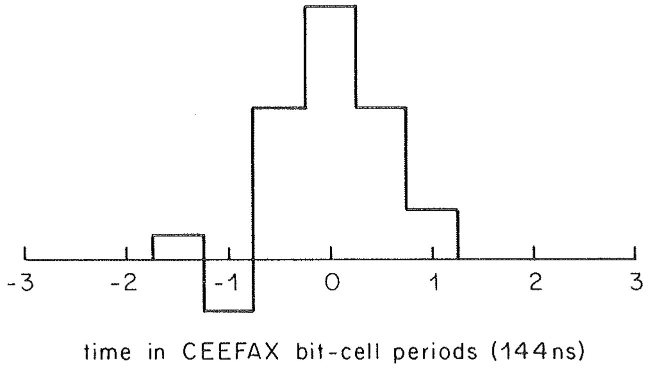


Fig. 18(b) - Output from transversal filter prior to (sin x)/(x) equaliser verted into return-to-zero form, so that each binary '1' lasts for half of one bit-cell (72 ns). The data is then applied to a 10-stage shift-register clocked at twice the CEEFAX data bit-rate (13·875 MHz).

The complementary outputs from each stage of the shift-register are connected to individual pick-off amplifiers. The gain of each amplifier can be varied continuously, from a positive to a negative value by altering the setting of the 500-ohm potentiometer (see Fig. 18(a)); when the potentiometer is in the middle of its range, the gain of the pick-off amplifier is zero. The outputs of the amplifiers are summed using a common busbar.

The experimental transversal filter was virtually identical to the ideal, shown in Fig. 17(a), except that the pulses passed along the delay line were rectangular rather than true impulses and the output resembled a "sampled-and-held" waveform, as shown in Fig. 18(b). The spectrum of this waveform compared to the ideal impulse waveform (see Fig. 17(b)) has a roll-off with increasing frequency that follows a (sin x)/(x) law. To correct for this effect the output of the experimental filter was passed through a simple lumped-element equaliser.

Using the transversal filter to generate different pulse-shapes was found to be very simple. For each pulse-shape, sample values at 13·875 MHz rate were calculated. A single repetitive pulse was then applied to the input of the shift-register and the signal prior to the (sin x)/(x) equaliser was observed on an oscilloscope. The tap coefficients were then adjusted in turn to give a "sampled-and-held" waveform with the correct sample values. After low-pass filtering at 6·9375 MHz, the correct pulse-shape was produced. For all the experimental work, the spectrum of the CEEFAX data signal was limited to 5 MHz and therefore a 5 MHz low-pass filter was used instead of a 6·9375 MHz low-pass filter.

The transversal filter could easily be set so that the eye-height of the CEEFAX data was within two or three per cent of the theoretical value. The circuit was able to operate satisfactorily with bit-rates up to about 20 Mbit/s with the appropriate clock-frequency for the shift-register and (sin x)/(x) equaliser.

APPENDIX II

1. Receiver performance

The design of the r.f., i.f. and demodulator circuitry of Teletext receivers is discussed in this Appendix. The improvements suggested are aimed at obtaining maximum data eye-height.

1.1. Distortions which affect data reception

There are three types of distortion commonly introduced in various parts of present-generation Teletext receivers.

(i) amplitude-response distortion
(ii) group-delay distortion
(iii) non-linear distortion

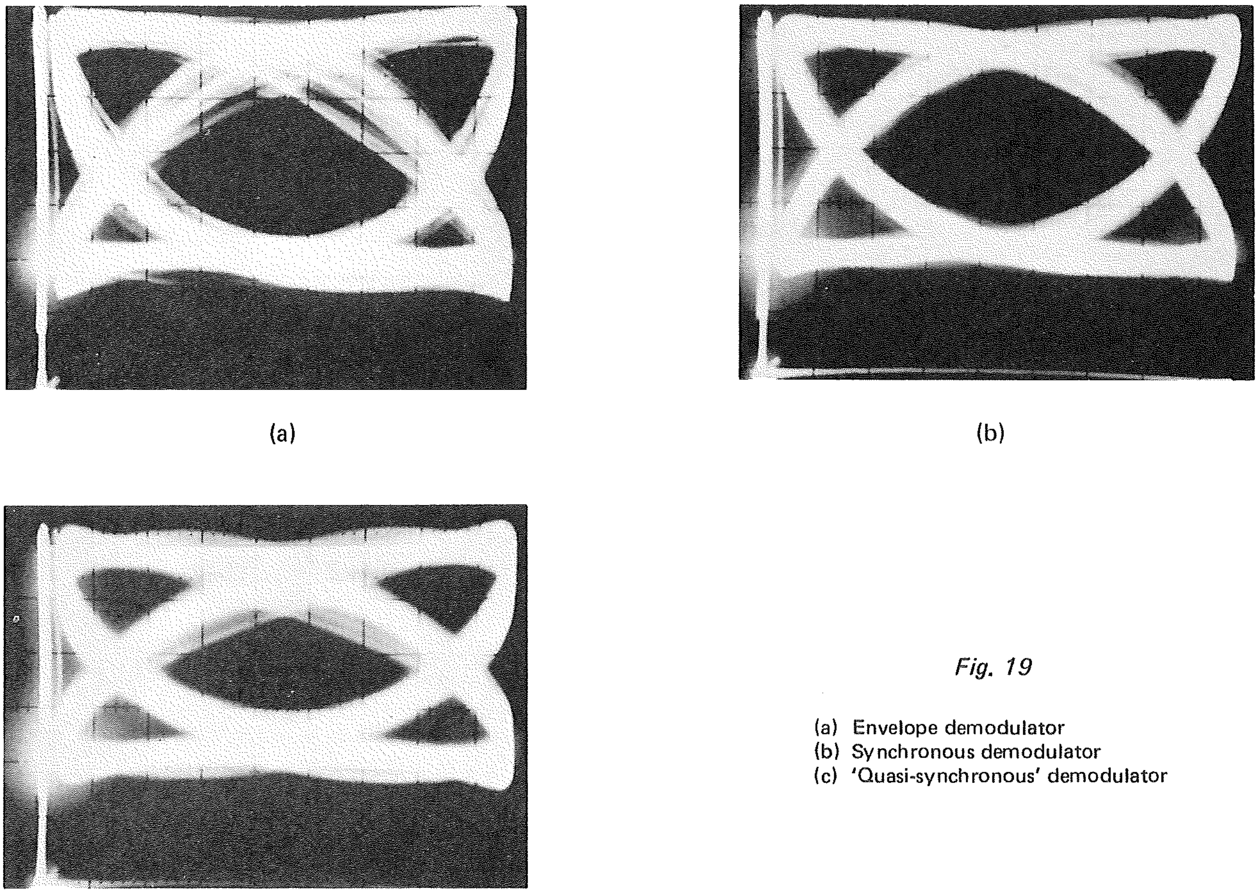
1.1.1. Amplitude-response distortion

The video amplitude response should be flat from a very low frequency to 5 MHz, for proper reception of data transmitted to the new standard recommended in this report. The flatness of amplitude response up to half the bit-rate (3·5 MHz) is particularly important. This is because repetitive data sequences have their predominant energy at discrete frequencies below 3·5 MHz. An amplitude ripple which causes, say, 5% attenuation of such a frequency will reduce eye-height by nearly 5%. Amplitude ripple below 3·5 MHz must be kept under 5% for less than 5% loss of eye-height.

The tolerance on amplitude response need not be so tight at higher video frequencies. However, it must be remembered that the loss in percentage eye-height can be much greater than the loss in percentage of data energy caused by high frequency attenuation. For instance a 1% loss of high-frequency video energy can result in up to 10% loss in eye-height because the components which make up the data spectrum are coherent. Consider for instance a data sequence having two frequency components one of which has a tenth of the amplitude of the other. Removing the smaller component can reduce the eye-height of the resulting data by 10% while only removing 1% of the energy.

1.1.2. Group-delay distortion

The video group-delay response of a Teletext receiver should be flat for video frequencies up to 5 MHz. Group-delay distortion reduces eye-height, increases peak-to-peak value, and shifts the optimum sampling-instant from the centre of the eye. Group-delay distortion for


(a)

(b)

(c)

Fig. 19

(a) Envelope demodulator
(b) Synchronous demodulator
(c) 'Quasi-synchronous' demodulator

frequencies up to half the bit-rate (3·5 MHz) is the most damaging. Its effect is less serious at high video frequencies and is roughly equivalent to losing energy at high video frequencies, as discussed in 1.1.1. above.

1.1.3. Non-linear distortion

The predominant non-linear distortion in television receivers occurs in the demodulator. If an envelope detector is used, severe quadrature distortion is present on the output video signal. Fig. 19(a) illustrates the effect of quadrature distortion caused by envelope demodulation, on the Teletext eye-pattern. There is a substantial loss of eye-height compared with synchronous demodulation as shown in Fig. 19(b). The symmetry of the waveform about a voltage level half-way between the level of binary '0' and binary '1' is also destroyed, making data acquisition more difficult. The eye-pattern obtained from a commercial integrated circuit 'quasi-synchronous' demodulator (Fig. 19(c)) shows similar but reduced non-linearity.

2. A specification for high-quality Teletext receivers

The specification quoted below for the various parts of a Teletext receiver will, if met, considerably reduce the various distortions described above. The aim is that there should be less than 5% loss of eye-height due to each individual distortion. It is difficult to predict the combined effect of the various distortions since eye-height losses do not necessarily add arithmetically.

2.1. The i.f. filter

(a) The i.f. filter should have a flat passband amplitude-response (outside the vestigial region) for video frequencies up to 5 MHz. Fig. 20 is a specification for the amplitude response of the i.f. filter. If the amplitude response lies within the limits indicated, the loss of eye-height should be less than 5%. It will be noticed that the tolerance required is particularly tight in the region between carrier-frequency, f_0, and −3·5 MHz of carrier frequency, for the reasons explained in Section 1.1.1.

(b) The i.f. filter should have a vestigial amplitude response which is accurately skew-symmetrical about vision carrier frequency. The tolerance required is explained in Fig. 20. The tolerances ensure that there is less than 5% of video amplitude-ripple in the region corresponding to the vestige. For the reasons explained in Section 1.1.1. this will result in less than 5% loss of eye-height.

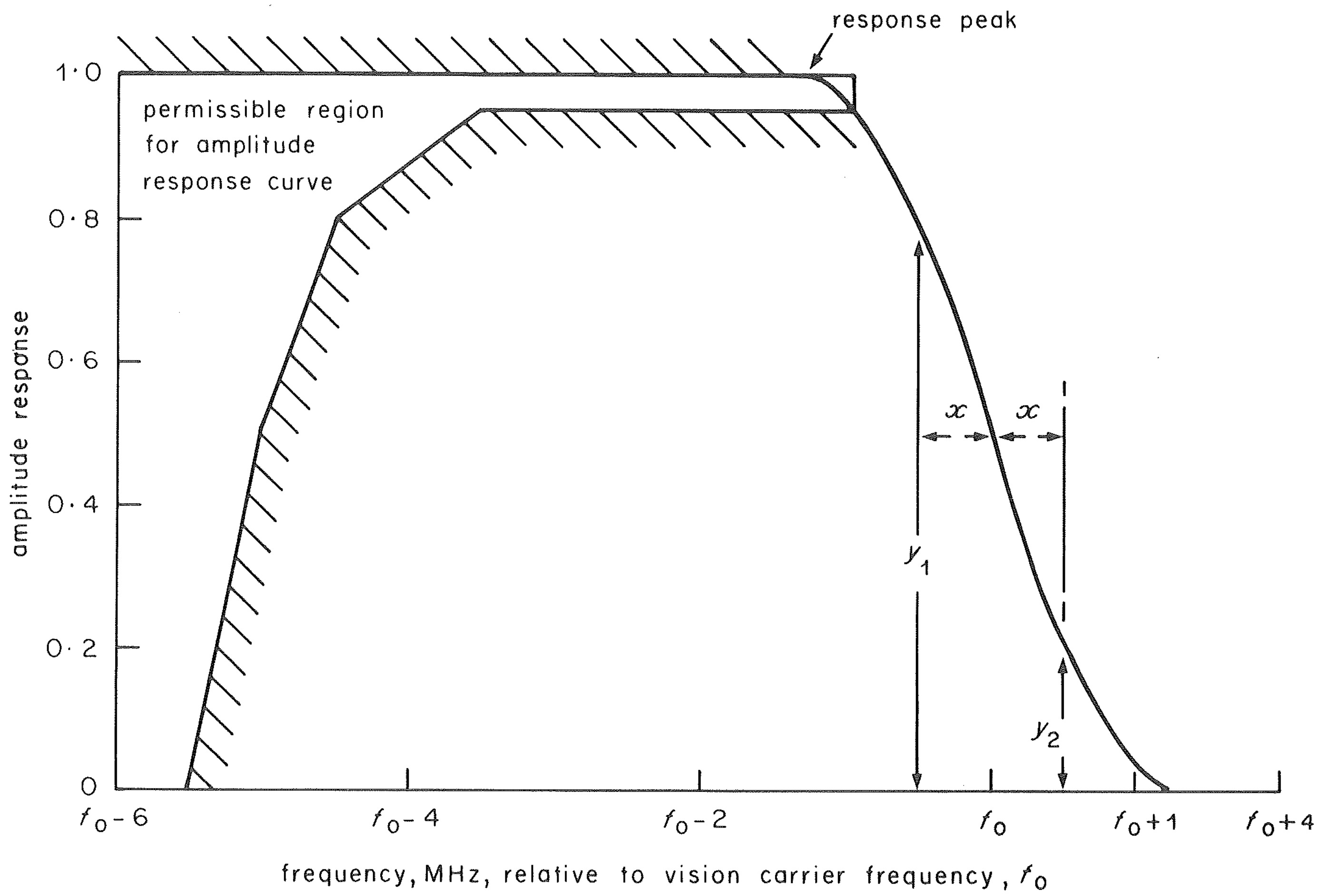


Fig. 20 - Amplitude response specification for Teletext receiver i.f. filters. Tolerance on skew symmetry of vestige $0{\cdot}95 < y_1 + y_2 < 1{\cdot}00$, i.e. maximum permissible deviation −0·4 dB

(c) The i.f. filter should have a flat group-delay response in the passband. Variations in group-delay should correspond to deviations from phase-linearity of less than a few degrees. Fig. 21 is a template for the group-delay response of the i.f. filter. If the group-delay response lies within the template, the loss of eye-height due to any deviations from flatness will be less than 5%. The tolerance specified is derived from the arguments described in Section 1.1.2.

2.2. The automatic-frequency-control (a.f.c.) circuitry

The a.f.c. circuitry should be capable of holding the tuning such that the vision carrier is placed very near to the frequency in the vestigial region where the i.f. response is at −6 dB relative to the response at midband. Any departure from correct tuning will cause ripples in the low-frequency part of the baseband video amplitude response, reducing the eye-height as explained in Section 1.1.1. A tuning tolerance of ±50 kHz is recommended.

2.3. The demodulator

The demodulator should have negligible non-linearity and a video bandwidth flat to 5 MHz. True synchronous detection gives the best linearity. Commercial integrated circuit 'quasi-synchronous' detectors can cause about 10% loss of eye-height. Envelope detectors must be ruled out as they result in a severe loss of eye-height.

2.4. UHF tuner, i.f. amplifier, video circuitry, etc.

The u.h.f. tuner, the i.f. amplifier, and the video circuitry should have bandwidths wide enough to have negligible effect on the overall amplitude and group-delay responses of the receiver. They should also be free from non-linearity at normal signal levels.

3. Receiver design

The design of Teletext receivers is discussed here and

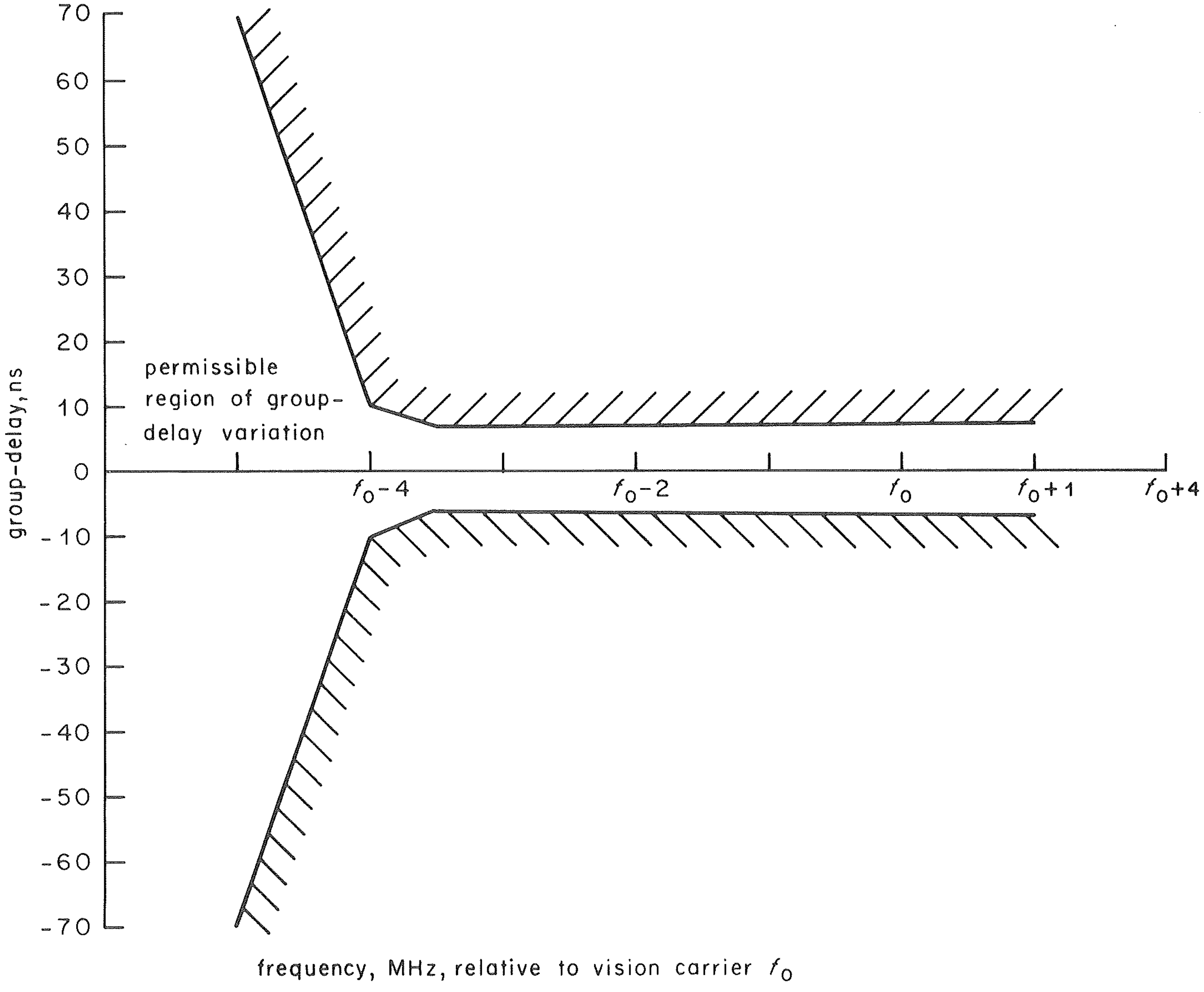


Fig. 21 - Group-delay response template for Teletext receiver i.f. filters

methods are suggested for achieving the specification outlined above.

3.1. The i.f. filter

Most lumped-element filters used in present-generation receivers suffer from severe group-delay distortion. They also have inaccurate vestigial characteristics and inadequate bandwidths. An i.f. filter which meets the specifications quoted in Section 2.1. will probably be a surface-acoustic-wave (SAW) device. These filters work on the transversal-filter principle. Hence, they can be designed to have a flat group-delay response, without any special compensation. The design of the amplitude response is also more flexible than with conventional lumped-element filters. Furthermore, the spread of characteristics in production is smaller than with lumped-element filters which require accurate alignment.

3.2. The a.f.c. circuitry

The a.f.c. circuitry must be properly designed and accurately aligned. The alignment procedure must be such as to set the i.f. vision carrier frequency at the frequency in the vestigial region which is at −6 dB relative to midband response of the i.f. filter, rather than at 39·5 MHz, (the usual vision carrier frequency). The a.f.c. circuitry used in many present generation receivers is not sufficiently positive or accurate. It is hoped that the development of synthesised local-oscillator integrated circuits, or phase-locked-loop methods (Section 3.3.) will improve the tuning accuracy of future receivers.

3.3. The demodulator

Demodulator linearity is important for good Teletext reception. Envelope detectors must be ruled out as they result in unacceptable degradation of Teletext reception, (see Section 1.3.). They also require i.f. filters and amplifiers with very tight specifications which can only be met by sacrificing other aspects of performance. For instance a deep sound trap is required which usually implies restricted video bandwidth.

The 'quasi-synchronous' detector integrated circuits on the market at present give some improvement. However, they suffer from a significant amount of non-linearity because of the way in which they obtain a carrier for synchronous demodulation. The vestigial sideband i.f. signal is filtered using a single tuned circuit at carrier frequency. This signal is then fed to a limiter and the output of the limiter is used as the demodulating carrier. Phase-modulation is present on the carrier because of the vestigial nature of the i.f. signal. Static phase errors are also usually present due to slight misalignment of the carrier recovery tuned circuit. Both these effects lead to a significant amount of non-linearity, and a consequent loss of eye-height.

Using a phase-locked-loop to obtain the carrier required for demodulation is one method of reducing non-linearity. A phase-locked-loop can be designed to have a much narrower bandwidth than the conventional tuned circuit used for carrier recovery. Consequently the phase-modulation on the recovered carrier is greatly reduced, leading to improved linearity. The phase-locked-loop can also be designed so as to ensure accurate tuning. There has been reference in the literature to an integrated circuit designed in the USA which uses this principle.[7]

3.4. UHF tuners

The design of u.h.f. tuner heads seems adequate except that they lack bandwidth for use with high-quality surface-acoustic-wave i.f. filters. Tilts of about 3 dB across the i.f. passband are not uncommon. The tilt should be reduced to under 1 dB.

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